example only and that, within the scope of any appended claims and equivalents thereto; the invention may be practiced other than as specifically described.

[0091] The phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. As used herein, the term "plurality" refers to two or more items or components. The terms "comprising," "including," "carrying," "having," "containing," and "involving," whether in the written description or the claims and the like, are open-ended terms, i.e., to mean "including but not limited to." Thus, the use of such terms is meant to encompass the items listed thereafter, and equivalents thereof, as well as additional items. Only the transitional phrases "consisting of" and "consisting essentially of," are closed or semi-closed transitional phrases, respectively, with respect to any claims. Use of ordinal terms such as "first," "second," "third," and the like in the claims to modify a claim element does not by itself connote any priority, precedence, or order of one claim element over another or the temporal order in which acts of a method are performed, but are used merely as labels to distinguish one claim element having a certain name from another element having a same name (but for use of the ordinal term) to distinguish claim elements.

~~**[0092]** What is claimed is:~~

CLAIMS

1. A method of maximizing draw solute recovery in an osmotically driven membrane system, the method comprising the steps of:

providing a first osmotically driven membrane system comprising a forward osmosis membrane and configured for receiving a first solution on a first side of the membrane and a concentrated draw solution on a second side of the membrane;

osmotically separating a solvent from the first solution using the concentrated draw solution, thereby forming a second solution on the first side of the membrane and a dilute draw solution on the second side of the membrane, wherein the second solution comprises at least one first ionic species of solute via reverse ion exchange through the membrane;

separating the dilute draw solution to recover at least one draw solute and the solvent, wherein the recovered solvent comprises at least one second ionic species of solute;

recycling the recovered at least one draw solute to the first osmotically driven membrane system;

providing a second osmotically driven membrane system comprising a reverse osmosis membrane;

pressurizing the recovered solvent in the second osmotically driven membrane system to recover a substantially pure solvent and a concentrated solution comprising the at least one second ionic species of solute;

recycling the concentrated solution comprising the at least one second ionic species of solute to the first osmotically driven membrane system, wherein the concentrated solution is added to the first solution, thereby resulting in the second solution comprising the at least one first ionic species of solute and the at least one second ionic species of solute;

balancing the at least one first species of solute with the at least one second species of solute to form additional removable draw solutes; and

separating the second solution to recover the additional draw solutes and a third solution.

2. The method of claim 1 further comprising the step of recycling the additional draw solutes into the concentrated draw solution.

3. The method of claim 1, wherein the step of separating the dilute draw solution comprises distillation.

4. The method of claim 1, wherein the concentrated draw solution comprises ammonia and carbon dioxide in a molar ratio of at least 1:1.

5. A system for osmotic extraction of a solvent from a first solution, comprising:

a forward osmosis system comprising:

a first chamber having an inlet fluidly connected to a source of the first solution;

a second chamber having an inlet fluidly connected to a source of a concentrated draw solution; and

a semi-permeable membrane system separating the first chamber from the second chamber;

a first separation system fluidly coupled to the forward osmosis system downstream of the second chamber and configured to receive a dilute draw solution therefrom and to separate the dilute draw solution into draw solutes and a solvent stream;

a pressure exchanger fluidly coupled to the separation system and configured to pressurize and transport the solvent stream;

a reverse osmosis system fluidly coupled to the pressure exchanger and comprising:

a first chamber configured for receiving the pressurized solvent stream;

a semi-permeable membrane coupled to the first chamber; and

a second chamber coupled to the semi-permeable membrane and configured for receiving a solvent fluxed through the membrane, wherein the first chamber of the reverse osmosis unit is fluidly coupled to the first chamber of the forward osmosis unit to provide at least a portion of the first solution; and

a second separation system fluidly coupled to the first chamber of the forward osmosis system and configured for receiving a concentrated first solution therefrom and removing at least one of draw solutes and a product stream from the concentrated first solution.

6. The system of claim 5 further comprising a recycling system in fluid communication with the second separation system for returning the separated draw solutes to the concentrated draw solution.

7. The system of claim 5, wherein the concentrated draw solution comprises ammonia and carbon dioxide in a molar ratio of at least one to one.

8. The system of claim 5, wherein at least one of the first and second separation systems comprises at least one of a distillation column or a contact membrane.

9. A method of treating wastewater, comprising:

introducing wastewater having a high biochemical oxygen demand or a high chemical oxygen demand on a first side of a semi-permeable membrane;

introducing a concentrated draw solution comprising ammonia and carbon dioxide at a molar ratio of at least one to one on a second side of the semi-permeable membrane to maintain a desired osmotic concentration gradient across the semi-permeable membrane;

promoting flow of at least a portion of the wastewater across the semi-permeable membrane to form a second solution on the first side of the semi-permeable membrane and a dilute draw solution on the second side of the semi-permeable membrane; and

introducing at least a portion of the dilute draw solution to a separation operation to recover draw solutes and a solvent stream.

10. The method of claim 9, further comprising introducing the second solution to a secondary process including at least one of an incinerator and an anaerobic digester.

11. The method of claim 10, further comprising providing heat generated during the secondary process to the separation operation.

12. A forward osmosis process comprising the steps of:

introducing a first solution comprising a solvent and at least one solute on a first side of a semi-permeable membrane;

introducing a plurality of seeds to the first solution;

introducing a concentrated draw solution to a second side of the semi-permeable membrane;

promoting nucleation of the at least one solute in the first solution; and

promoting a flow of at least a portion of the solvent across the semi-permeable membrane to form a second solution on the first side of the semi-permeable membrane and a dilute draw solution on the second side of the semi-permeable membrane.

13. The process of claim 12, further comprising the step of directing at least a portion of the dilute draw solution to a separation unit to recover at least one of a solvent stream or draw solutes.

14. The process of claim 13, further comprising the step of reintroducing draw solutes into the concentrated draw solution on the second side of the semi-permeable membrane to maintain a desired molar ratio in the concentrated draw solution.

15. The process of claim 12 further comprising the step of recovering at least a portion of the at least one solute precipitated out of the first solution.

16. The process of claim 15, wherein the step of recovering the precipitated solutes comprises further processing of at least one of the solute or the first solution.

17. A system for the processing of a solution using osmosis, the system comprising:

a forward osmosis module comprising:

a first chamber in fluid communication with a source of a first solution comprising a solvent and at least one solute;

a second chamber in fluid communication with a concentrated draw solution; and

a semi-permeable membrane coupling the first chamber and the second chamber; and

means for introducing a plurality of seeds into the first chamber, wherein the plurality of seeds cause nucleation of at least a portion of the at least one solute when the first solution is introduced into the first chamber.

18. The system of claim 17 further comprising a separation module in fluid communication with the second chamber for recovering at least one of a solvent stream and draw solutes.

19. The system of claim 18 further comprising means for recycling draw solutes into the concentrated draw solution.

20. The system of claim 17 further comprising a recovery module in fluid communication with the first chamber for recovering precipitated solutes.

21. An apparatus for the treatment of a solution using osmosis comprising:

a chamber configured for receiving a first solution comprising a solvent and at least one solute;

a membrane module disposed within the chamber and comprising a semi-permeable membrane having an exterior surface in fluid communication with the first solution and an interior surface for receiving a concentrated draw solution; and

means for introducing a plurality of seeds into the chamber, wherein the plurality of seeds cause nucleation of at least a portion of the at least one solute in the first solution in the chamber.

CLAIMS

1. A method of maximizing draw solute recovery in an osmotically driven membrane system, the method comprising the steps of:

providing a first osmotically driven membrane system comprising a forward osmosis membrane, the system configured for receiving a first solution comprising a solvent on a first side of the membrane and a concentrated draw solution on a second side of the membrane;

osmotically separating the solvent from the first solution with the concentrated draw solution via an osmotic concentration gradient across the membrane, thereby forming a second solution on the first side of the membrane and a dilute draw solution on the second side of the membrane, wherein the second solution comprises at least one first ionic species of solute via reverse ion exchange through the membrane;

recovering at least one draw solute and the solvent from the dilute draw solution, wherein the recovered solvent comprises at least one second ionic species of solute;

recycling the recovered at least one draw solute to the first osmotically driven membrane system;

providing a second osmotically driven membrane system comprising a reverse osmosis membrane;

pressurizing the recovered solvent in the second osmotically driven membrane system to recover a substantially pure solvent and a concentrated solution comprising the at least one second ionic species of solute;

recycling the concentrated solution comprising the at least one second ionic species of solute to the first osmotically driven membrane system, wherein the concentrated solution is added to the first solution, thereby resulting in the second solution comprising the at least one first ionic species of solute and the at least one second ionic species of solute;

ionically balancing the at least one first species of solute with the at least one second species of solute to form additional removable draw solutes; and recovering the additional draw solutes and a third solution from the second solution.

2. The method of claim 1 further comprising the step of recycling the additional draw solutes into the concentrated draw solution.

3. The method of claim 1, wherein the step of recovering at least one draw solute and the solvent from the dilute draw solution comprises distillation.

4. The method of claim 1, wherein the concentrated draw solution comprises ammonia and carbon dioxide in a molar ratio of at least 1:1.

5. A system for osmotic extraction of a solvent from a first solution, comprising:

a forward osmosis system comprising:

a first chamber having an inlet fluidly connected to a source of the first solution comprising the solvent;

a second chamber having an inlet fluidly connected to a source of a

concentrated draw solution, the concentrated draw solution having an osmotic concentration greater than the first solution; and

a semi-permeable membrane separating the first chamber from the second chamber, wherein the greater osmotic concentration causes separation of the first solution and the formation of a dilute draw solution in the second chamber and a concentrated first solution comprising at least one first ionic species of solute in the first chamber;

a first separation system fluidly coupled to the forward osmosis system downstream of the second chamber and configured to receive the dilute draw solution therefrom and to separate the dilute draw solution into draw solutes and a solvent stream comprising the solvent from the first solution and at least one second ionic species of solute;

a pressure exchanger fluidly coupled to the separation system and configured to pressurize and transport the solvent stream;

a reverse osmosis system fluidly coupled to the pressure exchanger and comprising:

a first chamber configured for receiving the pressurized solvent stream;

a semi-permeable reverse osmosis membrane coupled to the first chamber; and

a second chamber coupled to the semi-permeable reverse osmosis membrane and configured for receiving a solvent fluxed through the reverse osmosis membrane, wherein the first chamber of the reverse osmosis system is fluidly coupled to the first chamber of the forward osmosis system to provide reverse osmosis concentrate comprising a concentrated solvent stream and the at least one second ionic species of solute to the first chamber of the forward osmosis system as at least a portion of the first solution, wherein the at least one second ionic species of solute ionically balances with the at least one first ionic species of solute to form additional draw solutes in the first chamber of the forward osmosis system;

a second separation system fluidly coupled to the first chamber of the forward osmosis system and configured for receiving the concentrated first solution and the additional draw solutes therefrom and removing at least one of the additional draw solutes and a product stream from the concentrated first solution; and

a first recycling system in fluid communication with the second separation system for returning the additional draw solutes to the concentrated draw solution.

6. The system of claim 5, wherein the concentrated draw solution comprises ammonia and carbon dioxide in a molar ratio of at least one to one.

7. The system of claim 5, wherein at least one of the first and second separation systems comprises at least one of a distillation column or a contact membrane.

8. The method of claim 1, wherein the at least one first ionic species of solute comprises NH_4^+.

9. The method of claim 1, wherein the at least one second ionic species of solute comprises at least one of Na^+ or CO_3^-.

10. The method of claim 1 further comprising the step of introducing a plurality of seeds to the first side of the forward osmosis membrane.

11. The method of claim 1, wherein the step of recycling the recovered at least one draw solute comprises mechanical vapor recompression of the recovered at least one draw solute.

12. The system of claim 5, wherein the at least one first ionic species of solute comprises NH_4^+.

13. The system of claim 5, wherein the at least one second ionic species of solute comprises at least one of Na^+ or CO_3^-.

14. The system of claim 5 further comprising means for introducing a plurality of seeds to the first chamber.

15. The system of claim 5 further comprising a second recycling system in fluid communication with the first separation system for returning the separated draw solutes to the forward osmosis system.

16. The system of claim 15, wherein at least one of the first and second recycling systems comprises a compressor.